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Nonlinear Dynamical Systems Analysis of Seafloor Topography

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Abstract

In this project, nonlinear dynamical systems analysis was applied to bathymetric data from the Mid-Atlantic Ridge (MAR) in order to determine whether the processes generating seafloor crust can be explained with low-dimensional nonlinear models. The two phase project involved first the refinement and then the application of a noise reduction technique developed by Robert Cawley and Guan Hsu at the Naval Surface Warfare Center. The technique was successfully adapted to accept stacks of bathymetric profiles, and was applied to SeaBeam records collected between the Atlantic and Kane Fracture Zones. The results of the analysis indicated that the raw data is very high dimensional or nearly stochastic. This is interpreted to mean that the sum total of all processes generating seafloor topography can not be explained with a low dimensional model. This result led to the idea of isolating different seafloor generating processes before analysis. To this end, a wavelet decomposition technique was developed and applied to bathymetric data, which successfully isolated fault and seamount locations from the raw bathymetric data.

Long-Term Scientific Objectives

The oceanic crust, a complex, evolving surface, is created and shaped by interactions between materials in states ranging from fluid magmatism to brittle fracturing. The continuous buildup and release of stress through plate growth and faulting, overlain by sediments, produces seafloor topography which is varied and complex. We wish to find out if there are simple deterministic rules which govern the production of complex patterns in the seafloor. If so, this would lead to a new understanding of seafloor characteristics and begin a new approach to geophysical problems in mid-ocean ridge processes.

This applied research is attempting to 1) find if there is a deterministic signature in seafloor topography (beyond the depth/age curve), 2) constrain the effective number of degrees of freedom in the processes which control seafloor generation, and 3) determine how the governing system parameters are related to physical variables such as stress, lithosphere thickness and spreading rate.

Project Objectives

This research has focussed on finding and analyzing deterministic (regular, periodic or chaotic) and stochastic variations in seafloor bathymetry by using and developing non-linear analysis techniques. The purpose of this project was to refine the nonlinear analysis technique for use on bathymetric profiles from the Mid-Atlantic Ridge between the Kane and Atlantic Fracture Zones. The analysis was performed to detect any evidence for low-dimensional behavior in the processes generating the seafloor topography near the MAR. Low-dimensional behavior would indicate that the processes could be modeled with a simple nonlinear deterministic equation rather than as a stochastic process. This result would greatly increase our understanding of the processes generating ocean crust, and further modelling efforts to duplicate and predict ocean bathymetry.

Final Results

The local geometric noise reduction method for chaotic signal detection (Cawley and Hsu, Phys. Rev. A., 46,6, 1992)) looks for low dimensional signals by embedding a time series using a delay coordinate construction and performing local smoothing. The technique has been shown to be able to detect underlying nonlinear determinism up to signal to noise ratios of 1 in some cases. This method was modified for use on stacks of Mid-Atlantic Ridge bathymetric profiles. The noise reduction technique was applied to the center beam of SeaBeam bathymetric data from between the Atlantis and Kane Fracture Zones, and did not find any evidence for low-dimensional behavior in the signal. This means that either the processes generating seafloor bathymetry are very high dimensional (greater than 5), stochastic, or the signal to noise ratio is less than 1. The conclusion from this is that the complexity of the raw data cannot be explained by deterministic models using fewer than 5 variables, and in fact, stochastic models may be most appropriate. This finding led to the idea of isolating a single seafloor generating mechanism, faulting, and examining only this for low-dimensional behavior. To this end, a wavelet decomposition technique was developed and applied to isolate the fault locations in a bathymetric profile. The resulting wavelet analysis of a single center beam bathymetric profile was able to isolate fault and seamount locations but, it was determined that a full swath 2-dimensional wavelet analysis would be needed to separate faults from seamounts. However, the wavelet analysis of the single profile revealed anomalous crust which was explained as a relic spreading center (Little et al, 1993).

Publications

1. Little, S.A., P.H. Carter, and D.K. Smith, Wavelet analysis of a bathymetric profile reveals anomalous crust, *Geophys. Res. Letts.*, **20**, (18), 1915-1918, 1993.